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In-situ calibration of the CMS electromagnetic calorimeter

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Abstract

The CMS electromagnetic calorimeter (ECAL) is a key instrument to exploit the energy frontier represented by the LHC, expected to deliver proton-proton collisions at a centre-of-mass energy of 14 TeV. High performance of the ECAL, in particular precise energy measurement of electrons and photons, will enhance the discovery potential of CMS. In-situ calibration with physics events will be the main tool to minimize the constant term in the resolution function. The calibration strategies and the studies performed on simulated data to achieve this goal are presented.

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1 Introduction

The ECAL is a homogeneous electromagnetic calorimeter consisting of 61200 $PbWO_4$ crystals in the barrel and 17600 in the endcaps. In the barrel the crystals are grouped in 32 supermodules covering each 20^o in ϕ. The endcaps cover the pseudo-rapidity region up to η equal 3.0 and are divided in two halves (Dees) each containing 3662 crystals [1]. The calibration of the ECAL is a challenging operation involving many different techniques. The target precision can only be achieved using physics events. The main source of channel-to-channel response variation is given by the variation in scintillation light yield with irradiation. Over the period of time in which the physics events used to provide an intercalibration are taken, the response must remain stable and constant to high precision. The changes in crystal transparency are tracked and corrected using a laser monitoring system described elsewhere [2]. The final goal of the calibration strategy is to achieve the most accurate energy measurement for electron and photons. The reconstructed energy can be written as follows:

$$E_e = G \times F \times \sum c_i \times A_i$$

where A_i is the uncalibrated amplitude measured by the i-th crystal, G is a global absolute scale, F is a correction function depending on the type of particle, its position, its momentum and on the clustering algorithm used. The c_i coefficients represent the intercalibration relative to the i-th crystal.

2 Pre-calibration

During the assembly phase, a ^{60}Co source is used to measure the intercalibration constants c_i of each channel. The data is saved in the construction database. The LY measurement of each crystal is rescaled using the daily reference crystal measurements [3]. A resolution of about 4% is achieved with this method.

A more precise measurement of the intercalibration constants are obtained using data from the test-beam. This measurements can be used to check the precision achieved by laboratory estimations. Since the crystal response to electrons depends on the electron impact position, a correction function depending on the 2 lateral coordinates is used to rescale the energy. The rescaling is implemented by fitting the energy distribution as a function of the impact position to a 4-th order polynomial. The corrected response of the single crystal S_{corr} can be written as the measured energy S_{meas} times the correction function:

$$S_{corr} = S_{meas} \frac{P^{max}xP^{max}y}{Px(x)Py(y)}$$

where x and y are the measured positions of the incident electron in the two lateral coordinates, and $P^{max}x, y$ is the maximum of the polynomial along the two coordinates. Only the events impinging in a small central window are used. The intercalibration coefficients c_i are defined as the ratio of the mean value of the corrected response with respect to a reference value. The statistical uncertainty remains negligible (less than 0.1%) provided that at least 1000 events are taken per crystal.

Intercalibration coefficients for the supermodules in the barrel are also obtained using cosmic muons which are well aligned with the crystal axes [4]. Well aligned cosmic rays, giving a large signal in the crystal they pass through, are selected by requiring the maximum energy in the adjacent crystals to be below a certain threshold. In the region covered by the trigger, an agreement of about 3% was achieved with respect to the testbeam calibration.

3 In-situ calibration

Only the combination of several approaches based on the use of physics events can provide a calibration to the level of 0.5% in the constant term of the energy resolution function. In the following paragraphs, the different techniques that are foreseen to be used in CMS are described.

3.1 Calibration at startup

The fastest method to improve the precision of the intercalibration constants at the startup is to take advantage of the ϕ-symmetry of the energy deposited within rings at constant η. This technique consists in comparing the total energy deposited in each crystal with the mean of the distribution of total energies for all crystals at that pseudorapidity. This is achievable by using two choices of events: from random bunch crossings [5], and from Level-1 jet triggers [6]. A limit on the precision arises due to non-uniformities in ϕ, primarily from the inhomogeneity of tracker material, but also from geometrical asymmetries such as the varying off-pointing angle of endcap crystals, and the boundaries between barrel supermodules. These non-uniformities result in a precision in the intercalibration constants which cannot be reduced by increasing the statistics of the sample. It can be seen in Fig. 1 that without using any knowledge about the material distribution in the tracker, the limit on the precision is close to 1.5% throughout the barrel and between 3.0% and 1.0% for the fiducial region on the endcaps. It can be expected that the limit on the precision will be closely approached with a few tens of millions of events. This is equivalent to about 10 hours of data taking, under the assumption that 1 kHz of Level-1 band-width is allocated to single jet triggers.

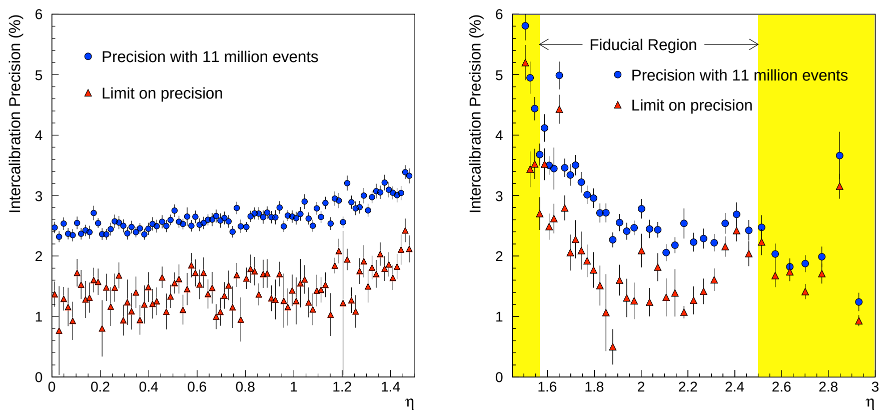

Figure 1: Precision limits in the barrel (left) and in the endcaps (right) using ϕ symmetry of the deposited energy from jet triggers.

3.2 Calibration using isolated electrons

Once the Tracker is fully operational and well aligned, the intercalibration of the ECAL can be precisely determined by comparing the momentum measurement of isolated electrons to the energy reconstructed in the associated energy cluster [8]. The main difficulty in using electrons for intercalibration is that they radiate in the tracker material in front of the ECAL and both the energy and the momentum measurement are affected. For these studies the ECAL energy was measured by summing the 5×5 array of crystals around the crystal with the maximum signal. In the endcaps the energy measured in the preshower and associated with the electron cluster is added to the energy summed in the 5×5 crystals matrix. To minimize the difference between track P_t and electron cluster energy, two algorithms have been considered: an iterative technique which was used for the in-situ calibration of the BGO crystals in the L3/LEP experiment [7] and a matrix inversion algorithm. The results, both in terms of precision and in terms of speed of algorithm, are similar, and show no dependence on the technique used. The event selection was based on variables which are sensitive to the amount of bremsstrahlung emission, and consequently measure the quality of the energy and momentum reconstruction. In the barrel, the calibration precision versus η achievable at a given integrated luminosity follows the tracker material budget distribution (Fig. 2a) while in the endcaps the precision is limited by the momentum resolution which is worse than in the barrel (Fig. 2b).

3.3 Calibration using $Z \to ee$

Using a data sample from Z decaying into two electrons it is possible to use the mass constraint to perform calibration tasks [9]. A number of different uses are envisaged like tuning of the algorithmic corrections for electron reconstruction or intercalibration of regions of the ECAL, for example as a complement to the ϕ symmetry method. An iterative method has been developed to tune the algorithmic corrections and to extract intercalibration constants of regions or individual crystals. In a start-up scenario, where the algorithmic correction factors are taken from Monte Carlo simulation, this sample can be used to obtain a preliminary estimate of the intercalibration factors between rings. Using events corresponding to an integrated luminosity of 2.0 fb^{-1} the distribution of the residual mis-calibration is shown in Fig. 3. The RMS spread of this distribution, corresponding to 0.6%, gives the achieved ring intercalibration precision.

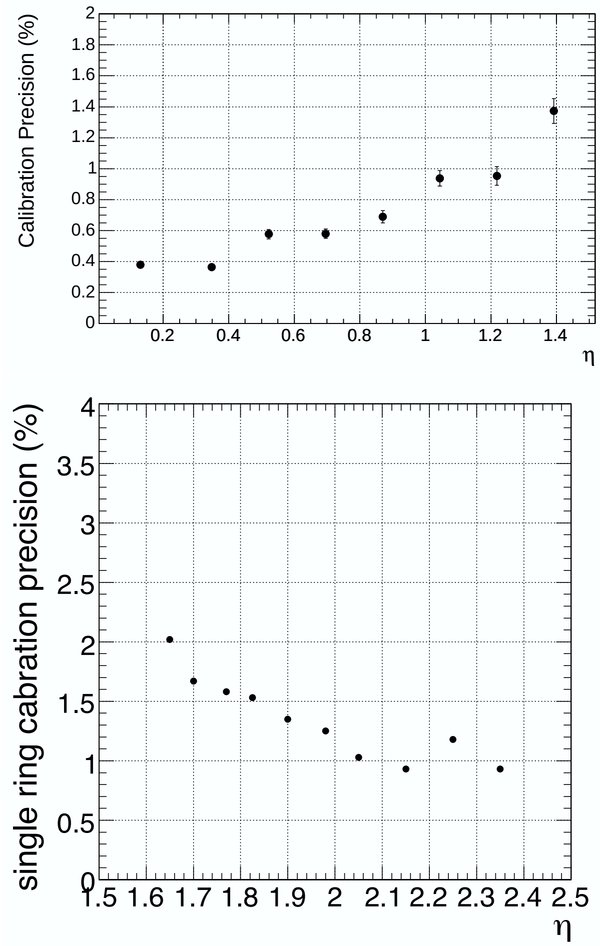

Figure 2: Calibration precision obtained in the barrel (top) and in the endcaps (bottom) using a dataset corresponding to 5 fb^{-1} and 7 fb^{-1} of integrated luminosity, respectively.

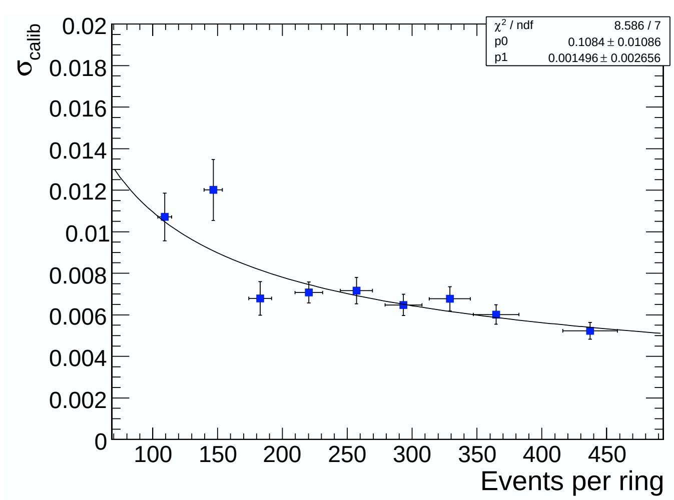

Figure 3: Precision on the intercalibration between rings as a function of the number of events per ring of crystals.

3.4 Intercalibration using π^0 and $\eta \to \gamma\gamma$ decays

The use of low mass resonances can supply additional tools for the ECAL calibration. Three main tasks can be envisaged: rapid intercalibration of all crystals, study of the effects of crystal transparency corrections, and monitoring of detector performance. The intercalibration obtained from low-energy π^0s is less sensitive to tracker material with respect to the intercalibration obtained using isolated electrons (decays of π^0 into photons that do not convert are unaffected). Converted low-energy photons give rise to low-energy electrons, which reach the ECAL far from the expected photon impact point because of the magnetic field. As a consequence, a selection of π^0s based on the selection of pairs of close-by electromagnetic clusters retains mostly either unconverted photons or photons which convert just in front of the calorimeter. For this reason, the energy resolution does not deteriorate and no energy bias is introduced at high η. The selection applies stringent shower shape cuts to the individual photon candidates. To reduce the combinatorial background, only π^0 candidates with small opening angles are considered. The reconstructed mass of the selected candidates is shown in Fig. 4 for two η regions in the ECAL barrel. The mass resolution is about 8% in each case. With 1000 events per crystal, a statistical precision of 0.5% can be estimated for the intercalibration constants. This needs to be demonstrated, and sources of systematic error must be investigated. Events from $\eta \to \gamma\gamma$ are also being studied. The signal has a much lower rate once the background is reduced sufficiently, but the mass resolution is about 3%. Decays $\eta \to \gamma\gamma$ should be a useful calibration tool at higher energy and may prove very useful in the endcap.

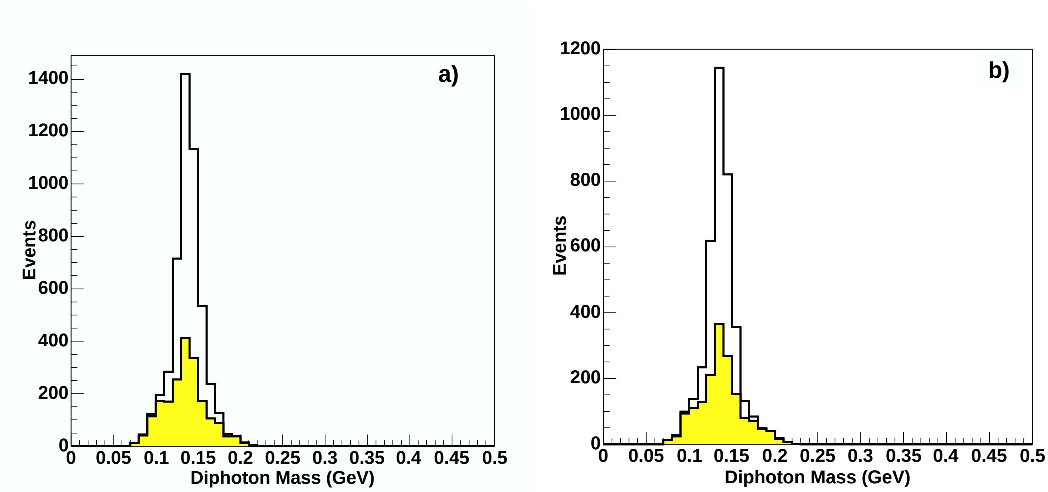

Figure 4: Di-photon invariant mass for: a) $|\eta| < 0.5$ and b) $0.5 < |\eta| < 1.0$.

3.5 Inner bremsstrahlung photons in Z boson decays to muons

A significant rate of high-pT photons with very little background and an energy which can be known independently of the ECAL is available in radiative decays of Z in two muons. These photons are being investigated as a valuable tool for various calibration related tasks, as well as a probe for measuring photon reconstruction efficiency. They can be used, for example, to intercalibrate different regions of the ECAL and to tune the various cluster correction algorithms and the overall energy scale. They can also be used to relate the energy scale of unconverted photons to that of electrons from converted photons.

4 Conclusions

An overview of the different approaches envisaged to calibrate the CMS electromagnetic calorimeter were presented. Starting from precalibrated crystals, different techniques will be implemented in-situ and they will rely on quality physics data to reach the best possible energy resolution. A fast intercalibration of rings of crystals at the same η is foreseen at the startup. The precise knowledge of the Z mass offer an important tool to intercalibrate the η rings as well as to calculate energy corrections. Low resonances into two photons offer an alternative calibration method less sensitive to the tracker material. Isolated electrons, mainly from W decays, will be used to reach the ultimate precision. The global calibration factor can be measured by using photons from radiative decays of $Z \to \mu\mu$.

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